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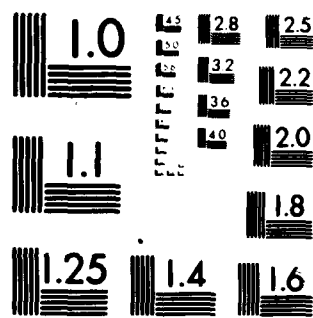
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CLIMATE VARIATIONS AND VARIABILITY:  
Facts and Theories

WAYNE V. BURT

30 JUNE 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A NATO-sponsored advanced study institute on climate variability was held in Erice, Italy (near Palermo, Sicily), 9-12 March 1980. Twenty-seven lecturers spoke to 76 other participants. Every facet of climate, its variability, and effects of variability on man were discussed. The majority of the papers presented were tutorial reviews based on published papers. Several of these papers are referenced in this report, while the body of this report concerns papers that were reporting unpublished research.		

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## CLIMATE VARIATIONS AND VARIABILITY: Facts and Theories

A NATO-sponsored advanced study institute on climate variability was held by the International School of Climatology (ICS) in Erice, Sicily (near Palermo), March 9-21, 1980. ICS is one of 80 "schools" that hold biennial study institutes at the nonprofit "Ettore Majorana" Center for Scientific Culture in Erice. One hundred four people attended the institute.

The headquarters of the center is picturesquely located in an early 16th-century convent in the center of the 0.3 km<sup>2</sup> (75-acre), triangular, mountain-top village of Erice. The mountain, Monte San Giuliano, rises abruptly from the sea to an elevation of 2500 ft, and dominates the wide fertile western part of Sicily. At the dawn of history the Greeks built there one of the largest temples in the ancient world, dedicated to Aphrodite, the goddess of love and beauty, and Erice became famous as a center of culture and religion throughout the Mediterranean world. Almost all remnants of the temple disappeared when a castle was built on its foundations in the 8th century. During medieval times Erice developed into a major Christian religious center with 50 churches, 4 convents, 4 monasteries, and a population of 12,000. Now it is almost deserted, with less than a thousand residents. Aside from a few tourists, the major "business" is the culture center which has conferences running throughout the year. It is an ideal place to hold a conference because after an hour's walk, one has seen it all; there is nothing to do but attend meetings!

The majority of the papers presented at the institute were tutorial reviews and other material based on published papers. Several of these papers are referenced below, but most of this report consists of reviews of papers reporting unpublished research.

The proceedings of the conference are scheduled to be published late this year by Reidel Publishing Company, Dordrecht, Holland.

Prof. W. Dansgaard, University of Copenhagen, presented an interesting paper on the results of paleoclimatic studies of polar ice cores. Ice cores from the Greenland ice sheet contain many kinds of airborne dust, including pollen, fungal spores, sea salt, volcanic ash, and micrometeorites. The rate of accumulation peaks in the summer months, giving an annual varve similar to varves in sediment cores. But as the ice sheet grows in depth, the bottom part flows laterally so that the annual layers become thinner the farther down a core one samples. Theoretically the ice records should go back for a million years in some places. Samples have been dated back fairly accurately for 50,000 years and with lesser accuracy for 150,000 years.

Ice accumulations have been rather uniform for the past 10,000 years and accuracy of absolute dating of the layers is matched only by dendrochronology. A detailed analysis of isotopes in ice cores reveals a seasonal cycle in the ratio  $O_{18}/O_{16}$ . Absolute dating is established by

counting summer peaks downward from the surface, almost like counting tree rings. The counts can be checked by fallout from historically known major volcanic eruptions, and are accurate to a fraction of 1%.

Volcanoes also eject large amounts of oxides of sulfur which fall out in the form of acid rain ( $H_2SO_4$ ). Acid varves can be located by scanning a split core for electrical conductivity. If 50-year means of core acidity are determined, the means can be considered as a 50-year index of volcanic activity: a high index indicates more than an average number of volcanic eruptions. Furthermore, particles from volcanoes remain in the atmosphere for many months and backscatter solar energy to space and tend to cool the lower atmosphere. Thus a higher acid index indicates colder than normal air temperature over a 50-year period. Major temperature changes in the past 1,000 years, known from historical documents, are faithfully recorded by the acid index. With this calibration, ice core acidity can be used to estimate climatic variations in the holocene period prior to historic documents.

Prof. John Woods, Institut für Meerskunde (Institute for Oceanography), University of Kiel, Germany, spoke on the memory of the oceans as related to the effects of the oceans on weather and climate. He defined analogs of climate and weather in the oceans in terms of a length scale,  $L_\beta = (2\mu/\beta)^2$ ,  $\beta$  is the rate of change in the Coriolis parameter with distance from the equator and  $\mu$  as a characteristic velocity, typically,  $L_\beta \approx 200$  m. Larger motions, the climate, are treated deterministically; smaller motions, the weather, are treated statistically. The memory of the smaller motions, based on error growth in numerical models, is estimated to be a few months at most. Such error growth may also limit the forecasts of changes in large-scale ocean circulation, responding to changes in atmospheric forcing on seasonal and longer time periods.

Surface heat anomalies frequently sink and are weakened during their temporary residence beneath the surface. This weakening can be expressed thermodynamically in terms of the rise in entropy associated with dilution of the anomalies by surrounding cooler water. The heat release to the atmosphere, when the anomalies return to the surface, is prolonged due to the drop in temperature. Woods concluded that the very long oceanic memory sometimes quoted by climatologists refers only to heat anomalies that are large enough to emerge with temperatures significantly higher than surrounding surface waters.

Dr. Jerome Namias, Scripps Institution of Oceanography, La Jolla, CA, discussed his historic forecast of the North American abnormal winter of 1976-77 ("Multiple Causes of the North American Abnormal Winter 1976-77", *Monthly Weather Review*, 106 [3], 279-293, 1978). Coastal waters off the west coast were unusually warm while west of 140° W long. they were cooler than normal. The baroclinicity from the strong sea surface temperature gradient strengthened fronts and cyclones. This gradient increased the upper level southerly flow and steered storms far north of their usual path. Vorticity redistribution from this wind system reinforced the west coast ridge and the trough over the eastern part of

the US with recurrent outbreaks of arctic air and attendant snow. The high albedo and refrigerating effect from the snowy surface enhanced the baroclinicity along the eastern sea board leading to stronger east coast storms. The "signals" of the oncoming winter's pattern were clear enough by November to permit a reasonably long-range forecast. At the end of the published paper, Namias stated, "If this report stimulates efforts to numerically model the complex synergistic events described, the author would feel that this synoptic study will have been most rewarding."

Following Namias' presentation, Dr. Joseph Smagorinsky, Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, NJ, presented the results of a 30-day prediction experiment modeling the January 1977 weather. He used a numerical model developed at Princeton in 1965 which takes into account radiation, large-scale convection, nonlinear horizontal viscosity and diffusion, a viscous boundary layer, orography, and real geography, and added to the model different drag coefficients for land and sea, surface hydrology, soil moisture, snow-albedo feedback, heat conduction in the soil, and vertical diffusion of heat and momentum. The sea-surface temperatures, the clouds, and the ozone distribution were prescribed as normal. The actual global weather on 1 January 1977 was used as the starting weather and the model was run for 30 days. The general circulation patterns over North America and adjacent oceans were faithfully reproduced to the end of the experiment, although by the end of the month some of the finer details of the weather were not reproduced.

Smagorinsky's paper was one of the highlights of the meeting. After the paper was presented, Namias gave a stirring testimony to the work of Smagorinsky and his group at Princeton, saying, "I feel privileged to have heard Dr. Smagorinsky's lecture which represents a breakthrough in meteorology and climatology of equal importance to the first short-range numerical forecast produced at Princeton a few decades ago—another event at which I was most fortunate to be present. For forty years I have wished for just such a numerical-dynamical forecast of mean atmospheric circulations a month in advance. The GFDL group at Princeton, NJ, especially Dr. Miyakoda and colleagues, have taken up the challenge and accomplished results exceeding expectations. Further experiments with other cases will be necessary to lead to operational use, but this occasion will probably take place before the end of the present decade."

Recent measurements of samples of ice cores (W. Berner, H. Oeschger, and B. Stauffer, "Information of the CO<sub>2</sub> Cycle from Ice Core Studies", *Radiocarbon*, in press) indicate that the CO<sub>2</sub> content of the earth's atmosphere during the last glacial period was about one third less than it is today. Professor Wallace Broecker of Columbia University, New York City, NY, presented an hypothesis for changes in the chemistry of the oceans which could have accounted for this change in CO<sub>2</sub>.

According to Broecker's putative scenario, as the sea level drops at the beginning of a glacial period, the organically rich continental shelf and estuarine bottom sediments could be scoured away. The PO<sub>4</sub><sup>3-</sup> in the sediments would go into solution in the sea water. As the PO<sub>4</sub><sup>3-</sup> is the limiting factor of organic production in the oceans, its increase

in concentration in upwelling regions would greatly increase the primary productivity. The  $\text{CO}_2$  in the ocean is taken up by plants to form carbohydrates.  $\text{CO}_2$  in the ocean is part of the same system as  $\text{CO}_2$  in the atmosphere and when a deficit occurs in the ocean,  $\text{CO}_2$  from the atmosphere will be absorbed at the ocean surface, with the consequent reduction of  $\text{CO}_2$  in the atmosphere. When the sea level rises again at the end of a glacial period, the sediments would be redeposited on the shelves and in estuaries and the reverse process would again increase the  $\text{CO}_2$  concentration in the atmosphere.

Professor A. Berger, Institute of Astronomy of the Catholic University of Louvain, Belgium, presented a paper entitled "Milankovitch Astronomical Theory of Paleoclimates" which is in press in *Vistas of Astronomy*, Arthur Beer, editor, Pergamon Press. Using a modern computer, he was able to employ more terms in the series describing variations in the earth's orbit than in any previous calculation. Berger recalculated the variations in solar energy reaching the earth due to changes in distance from the earth to the sun. Dips occur with frequencies of around 100,000, 41,000, and 21,000 years—the same frequencies with which significant peaks occur in the variation of climate (less significant peaks also occur at other frequencies). One stumbling block in the theory is that the 100,000 year peak in climate variation is relatively great while the change in solar energy is very slight at this frequency. Berger stated, "We do not claim that every peak in the Milankovitch curves produces an ice age. However, most probably when the influence is right and we have other influences due to internal processes, then the climatic regime which is already tilted toward an ice age dips into such a stage."

Professor John Imbrie, Brown University, Providence, RI, presented a second review paper on the Milankovitch theory (Imbrie, John and Imbrie, J.Z., "Modeling Climatic Response to Orbital Variations", *Science*, 207, 943-953). Imbrie was the only person at the meeting who was willing to go out on a limb and forecast climatic changes some distance in the future. His model predicted that the long-term cooling which began some 6,000 years ago will continue for the next 23,000 years.

Professor H. Flohn, University of Bonn, West Germany, presented a review paper on the mechanisms that may have brought about the benign climate over the Sahara that supported widespread cattle grazing in the millennia preceding 5,000 BC ("Vortrag Sahara-Tagung der Akademie der Wissenschaften und Literatur, Mainz", 1-4, April 1979, published in *Paleoecology of Africa*, Vol. 12, Ed. E.M. van Zinderen Bakker, Verlag A.A. Balkema, Rotterdam).

Professor R.G. Barry, Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO, presented a review of methods and progress in modeling climate (Barry, R.G., "Models in Paleoclimatic Reconstruction", *Paleogeography, Paleoclimatology, Paleoecology*, 17, 123-137, 1975; and Barry, R.G., et al, "Climate Change", *Reviews of Physics and Space Physics*, 17 [7], 1803-1813, 1979). The latter paper contains a long, up-to-date bibliography on paleoclimates, short-term climate fluctuations, and climate simulations.

Dr. N.J. Shackleton, Godwin Laboratory for Quaternary Research, Cambridge, England, presented a review paper on climate changes during the past seven million years largely based on analysis of deep-sea cores recently taken from the Deep-Sea Drilling Project (Shackleton, N.J., "Evolution of the Earth's Climate During the Tertiary Era", reprinted from the book *Evolution des Atmosphères Planétaires et Climatologie de la Terre*, Centre National d'Etudes Spatiales, Toulouse, France, 49-58, 1978).

Dr. R.A.S. Ratcliffe, Secretary of the Royal Meteorological Society, Bracknell, England, presented 2 papers. The first, Ratcliffe, R.A.S., Weller, J., and Collison, P., "Variability in the Frequency of Unusual Weather over Approximately the Last Century", *Quarterly Journal of the Royal Meteorological Society*, 104, 243-255, 1978, examined secular changes in: (1) Surface pressure anomalies over the northern hemisphere; (2) Surface temperatures for central England; and (3) Rainfall for England and Wales. No trend toward increased variability in any of these three parameters was found. The second paper, Ratcliffe, R.A.S., "Meteorological Aspects of the 1975-76 Drought" (in England), *Proc. Royal Society*, London, A 363, 3-20, 1978, presented the conclusion that the drought appeared to be a rare event rather than a symptom of climate change.

Bert Bolin reviewed the details of the carbon dioxide cycle in the earth's atmosphere and the oceans. His primary reference was Bolin, B., Degers, E.T., Kempe, S., and Ketner, P., "The Global Carbon Cycle", *SCOPE Report No. 13*, John Wiley and Sons, 1979. It contains numerous references to original papers. A second SCOPE report is due to be published by Wiley in the fall of 1980.

Namias gave a second paper, "Collaboration of Ocean and Atmosphere in Weather", *Proceedings, 9th Annual Conference of the Marine Technology Society*, 161-178, Washington, D.C., 1973. He emphasized that abrupt changes in weather regimes which may last for several years "are always associated with sea surface temperature transitions, and circumstantial evidence points to the oceans as the primary weather stabilizer.

Prof. R.E. Newell, MIT, Cambridge, MA, reviewed the interrelationships between the oceans and the atmosphere. More and more research workers believe that weather changes are frequently triggered by large patches of anomalous sea surface temperature and that the best way to improve weather forecasts is to better understand the relationship. Much long-range forecasting of weather takes into account the sea surface temperature distribution. (Newell, R.E., "Climate and the Oceans", *American Scientist*, 67, 405-416, 1979, and Newell, R.E., and Hsiung, J., "Fluctuations in Zonal Mean Sea Surface Temperature", *Rivista Italiana de Geofisica E Scienze Affini*, V, 151-155, 1978-79).

Dr. F. Niehaus, International Atomic Energy Agency, Vienna, Austria, discussed various scenarios for energy production in the future in order to estimate the increase of CO<sub>2</sub> and the resulting greenhouse effect that will warm the earth's atmosphere if the concentration of CO<sub>2</sub> builds up too much. He derived 2 limits. The lower limit is based on a worldwide

consumption of 30 TW ( $3 \times 10^{13}$  Watts) mainly from nuclear and solar energy by the year 2100. His model predicts a mean worldwide air temperature rise of  $0.5^{\circ}\text{C}$ . The upper limit allows for a consumption of 50 TW from fossil fuels by 2100 with an associated temperature increase of  $9.0^{\circ}\text{C}$ . (Niehaus, F., and Williams, J., "Studies of Different Energy Strategies in Terms of Their Effects on the Atmospheric  $\text{CO}_2$  Concentration", *J. Geophysical Research*, 84 (C6), 3123-3129, 1979.

Professor H.C. Fritts, Laboratory of Tree Ring Research, University of Arizona, Tucson, AZ, reviewed the state of the art in using tree-ring analysis as proxy data to reconstruct past climates. He pointed out that methods used in reconstructing past climates from tree-ring analysis were being rapidly improved through the use of isotope analysis and larger samples at any given location making it possible to accurately date climatic events in areas where it was not previously possible. (Fritts, H.C., *Tree Rings and Climate*, Academic Press, London, 1976; and Fritts, H.C., Lofgren, G., Gordon, G.R. and G.A., "Variations in Climate Since 1692 as Reconstructed from Tree Rings", *Quaternary Research*, 12 [1], 18-46).

There appeared to be a consensus that internal nonlinear dynamics between various climatic parameters can bring about climatic changes without external forcing. Climatic change may result from combinations of internal dynamics and external forcing. However, some climatic changes are clearly externally forced while others are clearly the result of internal nonlinear dynamics.

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